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A STATE-OF-THE-ART DATA SYSTEM FOR THE EVALUATION OF UNDERWATER--ETC(U)

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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

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A STATE-OF-THE ART DATA SYSTEM FOR THE EVALUATION OF UNDERWATER ACOUSTIC MATERIALS

by

Melvin H. Main, Jr.
and
Keith R. Musson

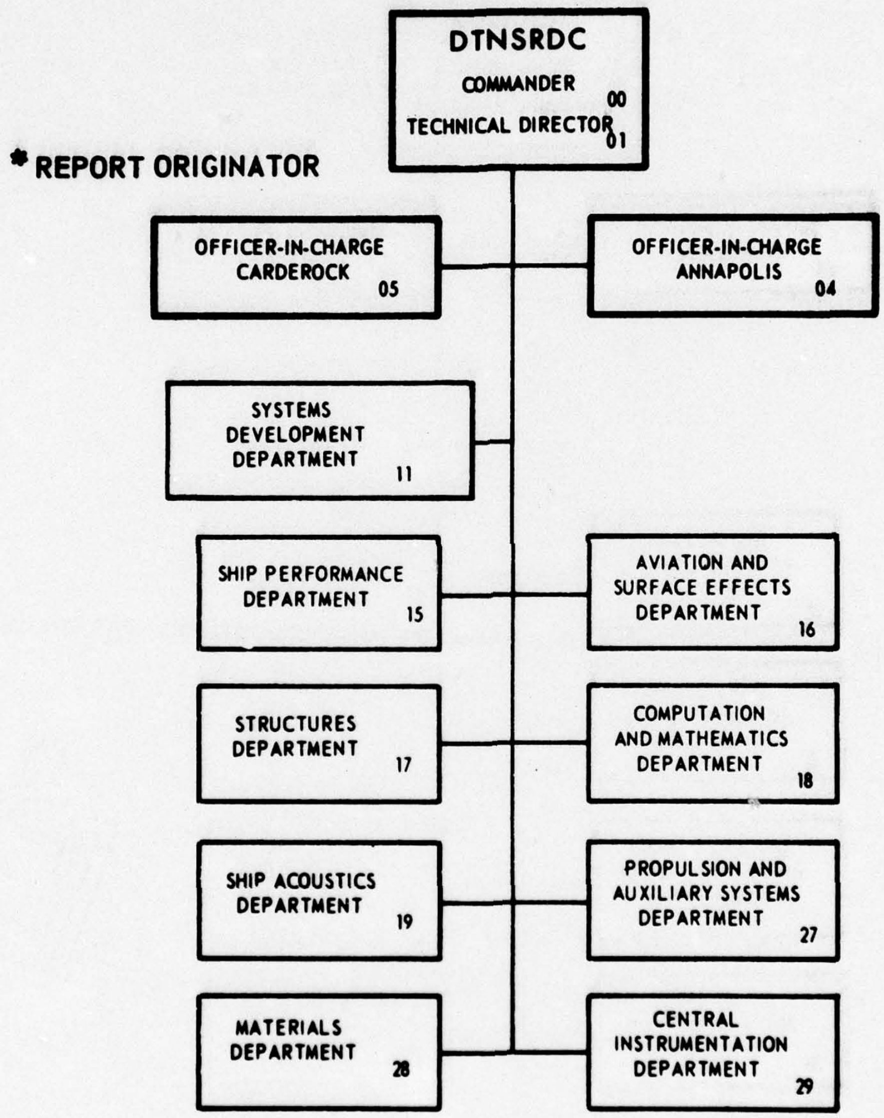
MATERIALS DEPARTMENT
Annapolis
RESEARCH AND DEVELOPMENT REPORT

February 1977

Report MAT-76-81

A State-of-the-Art Data System for the Evaluation of Underwater Acoustic Materials

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



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A computerized data acquisition system intended to completely automate the evaluation of underwater acoustic materials in the environment of a waveguide has been designed by the David W. Taylor Naval Ship Research and Development Center, Annapolis, Maryland. The system utilizes software sampling: a technique whereby the complete time-varying, analog representation of an

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(Authors)

ADMINISTRATIVE INFORMATION

This report was prepared in connection with work authorized by the Naval Sea Systems Command (SEA 037) under Task Area SAS 54 001, Task 18350, DTNSRDC Work Unit 2843-108.

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ABSTRACT

A computerized data acquisition system intended to completely automate the evaluation of underwater acoustic materials in the environment of a waveguide has been designed by the David W. Taylor Naval Ship Research and Development Center, Annapolis, Maryland. The system utilizes software sampling; a technique whereby the complete time-varying, analog representation of an acoustic signal is converted into digital format by means of a digital oscilloscope and then transferred to a computer where it is processed under program control. Data reduction occurs simultaneously with data acquisition and is obtained in hard-copy format as well as in graphical form. Measurements, such as reflection loss, energy absorption, target strength reduction, and acoustic impedance, are incorporated into the system through software creation and require no additional hardware subsystems.

INTRODUCTION

Acoustic materials have been of interest since the 1930's when anechoic coatings were first placed in underwater service. Since that time, research and development programs have produced materials that vary in chemical and physical structure from the practical to the almost bizarre. Underwater acoustic materials have been theorized into a highly complex and technical science, but the corresponding technology of experimental analysis has lagged behind these phases of development.

Many research and development facilities rely primarily on manual techniques for the acoustic evaluation of underwater materials. The signals employed are usually in the form of tone bursts or pulses, and their evaluation requires constant operator intervention on several levels at each test point. The signals contain phase and amplitude information used to compute the acoustic properties of materials. Data are most often taken by an operator from a visual display. Once recorded, the data are reduced point by point and transcribed into the desired format at a remote location. These techniques are tedious and subject to operator error, and the analysis of a material may require several days after the completion of acoustic testing. The growing need for reduced measurement errors and analysis time is stimulating the rapid replacement of such techniques by computer-controlled acquisition systems.

A number of computerized data systems are under development and/or in operation. Most depend heavily on analog subsystems for the actual measurement of acoustic signals. The instrumentation in these systems is more sophisticated, complex, and

elaborate than that incorporated in manual systems. In these systems the primary duty of the computer is to monitor, and record with time, the data provided by the subsystems. In most instances, the computer also provides for data reduction and transcription. This process occurs (at least in part) some time after data acquisition, usually a period of hours. The control of the test and its parameters is still to a great extent the responsibility of the operator. A great deal of the gain in accuracy and analysis time achieved with these systems is lost in operating efficiency due to the monitoring of extensive instrumentation, segmentation of data reduction, transcription, and lack of automated control.

THE DTNSRDC COMPUTER SYSTEM

A different kind of data system exists at the David W. Taylor Naval Ship Research and Development Center, Annapolis, Maryland. The system represents, to a great extent, innovations introduced by the authors of this report. It is designed to completely automate the acoustic evaluation of underwater materials in the environment of a waveguide. A conceptual diagram of the data system and associated test facility appears as figure 1.

In comparison to similar systems, the DTNSRDC system is compact, uncomplicated, reliable, and efficient in design. Such time as may be required for repair, maintenance, or modification seldom exceeds an hour or two. One reason is software sampling, a technique in which the complete time-varying, analog representation of an acoustic signal is converted into a digital format and then transferred to a computer system where it is processed under program control. Software sampling eliminates the need for complex analog subsystems and provides the capability to operate on the same signal with any number of varied measurement techniques. By employing this technique, each pulse in the signal experiences the same conditioning and is not subject to the error induced by time-varying coherent noise. Software sampling is implemented in the DTNSRDC system through the Nicolet digital oscilloscope, model 1090/93. In effect, this instrument is the fastest analog-to-digital converter at present commercially available. It is capable of capturing an analog signal at a maximum rate of 2 MHz (megahertz) and converting it into 4096 twelve-bit words. This provides the DTNSRDC facility with sufficient resolution for making phase measurements at frequencies exceeding 20 kHz (kilohertz). Also, all the digital input/output and storage control capabilities of the Nicolet are designed for remote programming (TTL (transistor/transistor logic) compatible). Complete specifications for the model 1090/93 Nicolet are given as appendix A.

The DTNSRDC system is, to a large extent, automated. Automation extends past process control and data acquisition. Reduction of the data occurs simultaneously with acquisition and is

displayed in hard-copy format on the console terminal. Immediately following the acquisition/reduction process, the data are transcribed into the desired format under program control and output by the system onto a Hewlett Packard 7046 x-y recorder.

OPERATIONAL SEQUENCE

Before the hardware interfacing of the system can be explained to a layman, a conceptual understanding of system operation is necessary. The operational sequence is as follows (refer to figure 1):

1. The acoustic material to be tested is inserted in the waveguide, and provided with either water or air termination, as desired.

2. The waveguide is sealed and brought to the desired temperature and pressure.

3. According to the specific measurement, system software is called into the computer central processing unit (CPU), and the limiting test parameters (i.e., initial frequency, final frequency, frequency increment, number of test pressures, and testing temperature limits) are selected and initiated via the console terminal.

4. Under program control, the Rockland model 5100 frequency synthesizer is set to the initial test frequency, and the multichannel filter is set to the upper and lower band-pass frequencies.

5. The CW (continuous wave) (pure-tone) signal from the synthesizer passes through a General Radio 1396B tone-burst generator where it is continuously gated into a preselected pulse at such a rate that each pulse completely decays in the waveguide before the next is generated. The signal is then applied through a McIntosh MI-75 power amplifier to a Celesco LC-50 transducer located at the base of the waveguide.

6. The acoustic pulse generated by the transducer propagates through the water in the waveguide and impinges on a Celesco LC-10 hydrophone which detects the signal both before and after interacting with the test specimen until it decays with time. The signal from the LC-10 hydrophone then passes through a Massa AM-1 amplifier and then the Rockland filter to be delivered finally to the analog input of the Nicolet oscilloscope.

7. The DECLAB 11/10 computer system loads the proper test parameters into the system devices and accepts the next SYNC pulse from the tone-burst generator. The computer then stores the actual testing temperature as measured by the Doric DS-300 temperature indicator and after delaying x-number of microseconds provides a pulse to trigger the Nicolet. After it

is triggered, the Nicolet samples the signal at its analog input at y-number of microseconds per point and stops when 4096 digital points have been taken and stored in its memory. The values for "x" and "y" are preset parameters of the particular test which are chosen to ensure the inclusion of the appropriate incident, reflected, and transmitted pulses in the signal now stored in the Nicolet.

8. The Nicolet is instructed by the computer program to transfer the signal stored in its memory to the core memory of the computer, one word at a time, until the entire signal resides as a one-dimensional array in core.

9. Under program control, the temperature is tested to determine if the last acquisition cycle was within prescribed temperature limits. The signal is then sampled for relative amplitudes and phases among the appropriate pulses of the signal. Still under program control, these signals are employed to calculate by suitable mathematical relationships the desired acoustic properties of the material tested. The results of the calculations, the measured input values, and the test parameters are then recorded as output in the desired format on the console terminal. The calculated values are retained in core for later use.

10. The computer resets the synthesizer and multichannel filter to the next frequency, as directed by the limiting test parameters which were selected at the beginning of the operation sequence.

11. The sequence reverts to step 5. and cycles through steps 5., 6., 7., 8., 9., and 10. until the material has been tested at the last prescribed frequency.

12. The software now manipulates the stored, calculated values into a number of formats that are necessary to the analysis of the material. Each representation of these values is simultaneously displayed on a Hewlett Packard 7046 x-y plotter.

13. The remaining test parameter (i.e., hydrostatic pressure) is incremented manually, and the operation sequence reverts to step 4. where it begins as many cycles as required to fulfill the scope of the measurement established in step 3. The sequence is now complete, and the system asks for new instructions.

From the standpoint of a computer specialist, the task of automation is simplified by the reduction in instrumentation that is afforded by software sampling. At present, only two instruments require direct computer intervention for the control of the test process, besides the Nicolet oscilloscope: (1) the Rockland frequency synthesizer, model 5100, and (2) the Rockland multichannel filter, system 816. The synthesizer has a variable

output of 10 volts peak-to-peak, with a 50-ohm source impedance in the frequency range of 0.001 Hz (hertz) to 2 MHz; and, 0- to 85-dB (decibel) attenuation of this output in 1-dB steps. The frequency selection is remotely programmable in 31 bits of BINARY or 37 bits of BCD (binary coded decimal) format. All input lines represent TTL logic levels. The multichannel filter consists of 16 channels, each either a high- or a low-pass filter. The DTNSRDC system uses only two channels. One is a Butterworth high-pass filter and the other is a Bessel low-pass filter, each having better than 48 dB per octave drop in amplitude response. The filter requires a maximum of 17 bits for full remote programming. All input lines represent inverted TTL logic levels. The cutoff frequency is selected by four bits, 8-4-2-1 code, of logic "1" (0.0 volt). The cutoff frequency multiplier is selected by four bits of logic "1." The possible selections are X.01, X.1, X1, and X10. The channel is selected by four bits, 8-4-2-1 code, of logic "1." Also, one bit at logic "1" will select remote programming control. There is usually one additional bit that is held at logic "0" (+5 volts). In doing so, all cutoff frequency data which have been loaded and stored internally; programming inputs need not be held constant. This bit at logic "1" loads cutoff frequency data.

HARDWARE INTERFACING

Hardware interfacing begins with the DECLAB 11/10 system (refer to figure 2). The system consists of eight basic TTL logic instruments. Each is connected to a common 56-line communication bus, UNIBUS. The system CPU is a PDP 11/10; a 16-bit word, interrupt driven machine with a real-time operating system and 24K words of core memory. The console terminal is the Digital Equipment Corporation LA36 Teletype, which is connected directly to the interrupt request lines of the CPU. Mass storage is provided by the Digital Equipment Corporation RK05 1.2-megaword disk pack and TU60 64-kiloword dual cassette drive. The computer system's communication link with the signal transmission and conditioning subsystem is provided by three Digital Equipment Corporation's DR11C input/output ports. Finally, graphic representations of data are made possible by the Digital Equipment Corporation AR11 digital-to-analog (DAC) converter.

The heart of digital communication between the computer and the subsystem device are the DR11C's. Each is composed of three 16-bit words. Each word has a unique address for the purpose of being identified by the CPU. One word is designated an "output" word; that is, BINARY data from the CPU is stored in this word awaiting transfer to a subsystem device. Another word is designated an "input" word; that is, BINARY or BCD data from any subsystem device is stored in this word awaiting transfer to the CPU. The remaining word is the "command status" word. This word controls the transfer process through four bits. Bits 15 and 7 (requests A and B) are the first bit of each byte, and can only

"read" responses from the subsystem. The unused DR11C will be employed in the future for the control of the hydrostatic pressure and of the amplitude of the CW signal from the synthesizer.

During step 4. of the operational sequence referred to earlier, the BINARY representation of the kilohertz and hertz settings for the Rockland 5100 synthesizer are placed by the CPU in the second byte of DR11C address 167762 and in the entire word of DR11C address 167772, respectively. Each of the bits used from both "output" words are hardwired to the appropriate inputs of the synthesizer in a 1-to-1 BINARY correspondence. When bit 1 of DR11C command status word, address 167770 provides a logic "1" to the "load" input of the synthesizer, the data on the kilohertz and hertz inputs are accepted and internally retained. The synthesizer now generates the prescribed CW signal. Following this process, the BINARY representation of the channel (only channels 0 and 1 are used), the cutoff frequency, and the cutoff frequency multiplier settings for the Rockland 816 filter are placed by the CPU in bit 11 of DR11C address 167772, in the first four bits of the first byte of DR11C address 167772 and in the first three bits of the second byte of DR11C address 167772, respectively. Again each of the bits used from the "output" word is hardwired to the appropriate inputs of the filter in a 1-to-1 BINARY correspondence. When bit 0 of DR11C status word address 167770 provides a logic "1" then a logic "0" to the "load" input of the filter, the data on all three sets of inputs are accepted and internally retained. The same procedure is repeated for the second channel. Step 4. is now complete.

Step 7. of the operation sequence is accomplished by hardwiring the BCD outputs of the least significant digit of the Doric DS300 temperature indicator to the first four bits of the first byte of DR11C address 167774 and the BCD outputs of the next significant digit of the same indicator to the first three bits of the second byte of the same DR11C address. The CPU samples this "input" word on each acquisition cycle and translates its BINARY configuration into a number readable by FORTRAN. When the temperature is within test limits, the CPU continuously samples bit 15 of the DR11C status word address 167760 which is hardwired to the SYNC pulse of the tone-burst generator. A SYNC pulse will place a logic "1" on bit 15. The CPU will respond after a preset delay by placing a logic "1" on, first bit 0, then bit 1, and then bit 2 of DR11C output word address 167762. Bit 0 is hardwired to the LIVE input of the Nicolet oscilloscope. A logic "1" on this input will clear the Nicolet of all previous instructions. Bit 1 is hardwired to the HOLD NEXT input of the Nicolet. A logic "1" on this input will instruct the scope to store in its memory the next signal it samples. Bit 2 is hardwired to the external trigger of the Nicolet. A pulse of ±0.25 to ±0.5 volt will trigger the scope.

The Nicolet now samples the signal at its analog input. When the sample is complete, a logic "1" is generated on the TC TAPE output of the Nicolet. This output is hardwired to bit 7 of DR11C status word address 167760.

Step 8. begins as logic "1" is sampled from bit 7 of DR11C address 167760 by the CPU. In response, the CPU places a logic "1" on bit 1 of the same DR11C address which is hardwired to the REMOTE TRIGGER input of the Nicolet. When logic "1" is placed on this input, the scope's program counter is set to zero and otherwise makes preparations for BINARY I/O. Next, bit 0 of DR11C address 167760 is clocked at a rate which is under program control. Bit 0 is hardwired to the WRITE CLOCK input on the Nicolet. When it senses the change between logic "0" and logic "1", it places the BINARY 12-bit word, whose address is in the program counter, on the 12 putput lines of the Nicolet and increments the program counter by one. The CPU now samples DR11C address 167764, which is hardwired to the Nicolet output lines, and transfers the word in it to a position in a one-dimensional core array that directly corresponds to that which it had with respect to all other samples in the core memory of the Nicolet. Bit 0 of DR11C address 167760 outputs another clock pulse, and the transfer process continues until the array of all 4096 words stored in the Nicolet is exactly duplicated in the core memory of the computer system. Each word in this core array now represents a voltage versus time sample of the acoustic signal. When the transfer process is complete, all bits on all DR11C's are set to logic "0" in preparation for the next cycle of the operating sequence.

Note that the 12 Nicolet output lines, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11, are hardwired to input bits 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 15, respectively, of DR11C address 167764. The remaining bits of address 167764 are hardwired to ground. When a positive number is represented on the outputs of the Nicolet, address 167764 will supply the proper logic to the CPU. When a negative number is represented on the same outputs, address 167764 will not supply the proper logic to the CPU because bits 11, 12, 13, and 14 of address 167764 do not undergo the process of 2's complement arithmetic, which is used to represent negative numbers, since the process is performed in the Nicolet. Due to the grounded bits on the DR11C address, each negative number transferred is incorrect by 30720. This is corrected by software, by adding a negative 30720 to the word once it resides in core.

No hardware is used until step 12. of the operation sequence. Here five lines are hardwired from the AR11 digital-to-analog converter to the HP 7046 plotter. Two of the lines are voltage outputs on a scale of ±5 volts that correspond to the x and y inputs on the plotter. Two other lines are the x and y returns to complete the data circuit. The remaining line controls the plotter's pen: UP corresponds to 0 volt, and DOWN corresponds

to ±5 volts. The data that pass through the AR11 on the way to the plotter are converted from BINARY code to ± (Z/1024) of 10 analog volts. Z is either the x or y output from the software. The digital-to-analog correspondence of the plotter scale is given as figure 3.

COMMENTS ON THE DTNSRDC SYSTEM

Based on the operation sequence and hardware interfacing as described above, the DTNSRDC system provides simultaneous process control, data acquisition, and data reduction/transcription of signals resulting from the acoustic evaluation of underwater materials. This system has greatly increased the scope of the DTNSRDC acoustic facility, at an expense much less than that of systems with comparable capabilities. Measurements, such as reflection loss, transmission loss, energy absorption, target strength reduction, and acoustic impedance, are incorporated into this system through software creation and modification without the incorporation of additional hardware or extensive operator intervention. Compared to manual systems designed for the same type of acoustic evaluation, the DTNSRDC system decreases: (1) measurement error by an estimated 99% based on the precision of amplitude readings, (2) system downtime by over 90% based on the number of specimens which can be tested per day, and (3) analysis time by a substantial margin over most manual systems. The DTNSRDC system is sophisticated, yet uncomplicated, and its potential is limited only by the creativity of the user.

1 - UNDERWATER ACOUSTIC MATERIAL
2 - CELESCO LC-10 HYDROPHONE
3 - CELESCO LC-50 TRANSDUCER
4 - WATER TEMPERATURE CONTROL SYSTEM
5 - PRESSURE LINE
6 - HEWLETT PACKARD 7046 x-y PLOTTER
7 - DORIC DS-300 TEMPERATURE INDICATOR
8 - ROCKLAND MULTI-CHANNEL FILTER, SYSTEM 816
9 - MASSA AM-1 AMPLIFIER
10 - DIGITAL EQUIPMENT CORPORATION, LA 36 TTY (CONSOLE TERMINAL)
11 - DIGITAL EQUIPMENT CORPORATION, DECLAB 11/10 COMPUTER SYSTEM (INCLUDES CPU)
12 - NICOLET INSTRUMENT CORPORATION, MODEL 1090/93 DIGITAL OSCILLOSCOPE
13 - ROCKLAND FREQUENCY SYNTHESIZER, MODEL 5100
14 - GENERAL RADIO MODEL 1396B TONE-BURST GENERATOR
15 - MCINTOSH MI-75 POWER AMPLIFIER

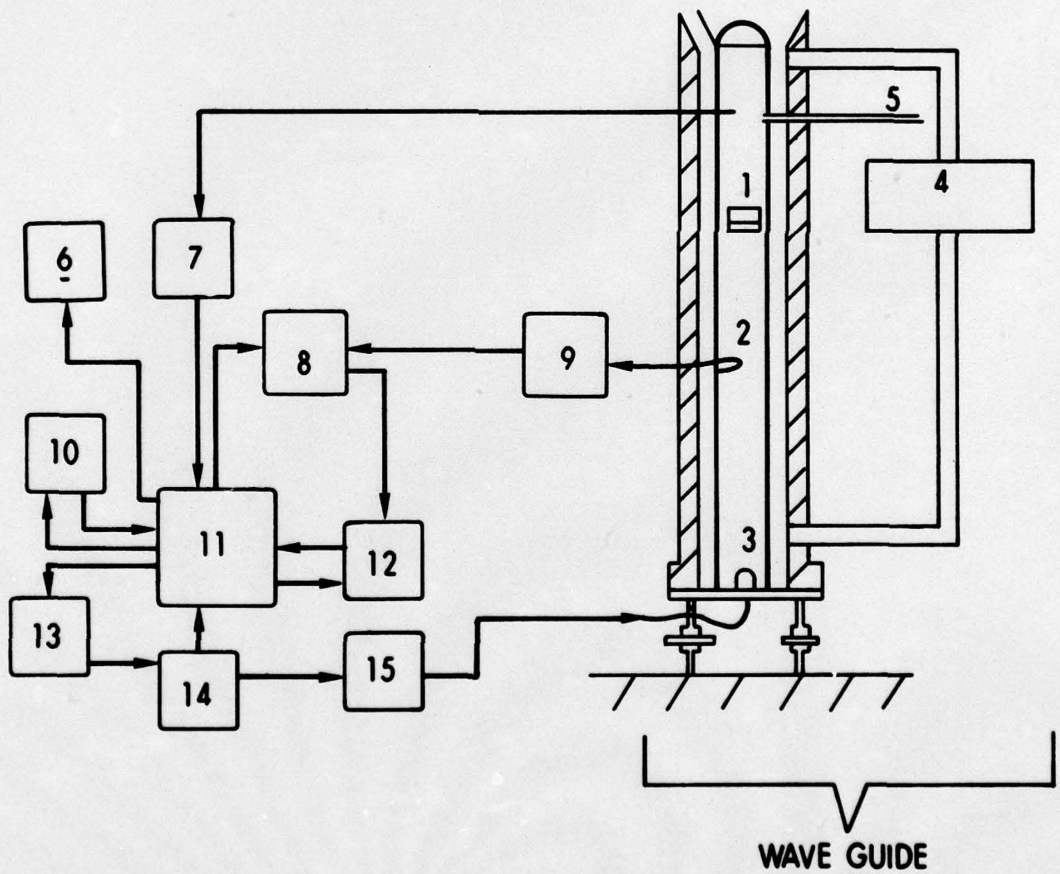

Figure 1 - Conceptual Diagram of the DTNSRDC Data System and Associated Test Facility

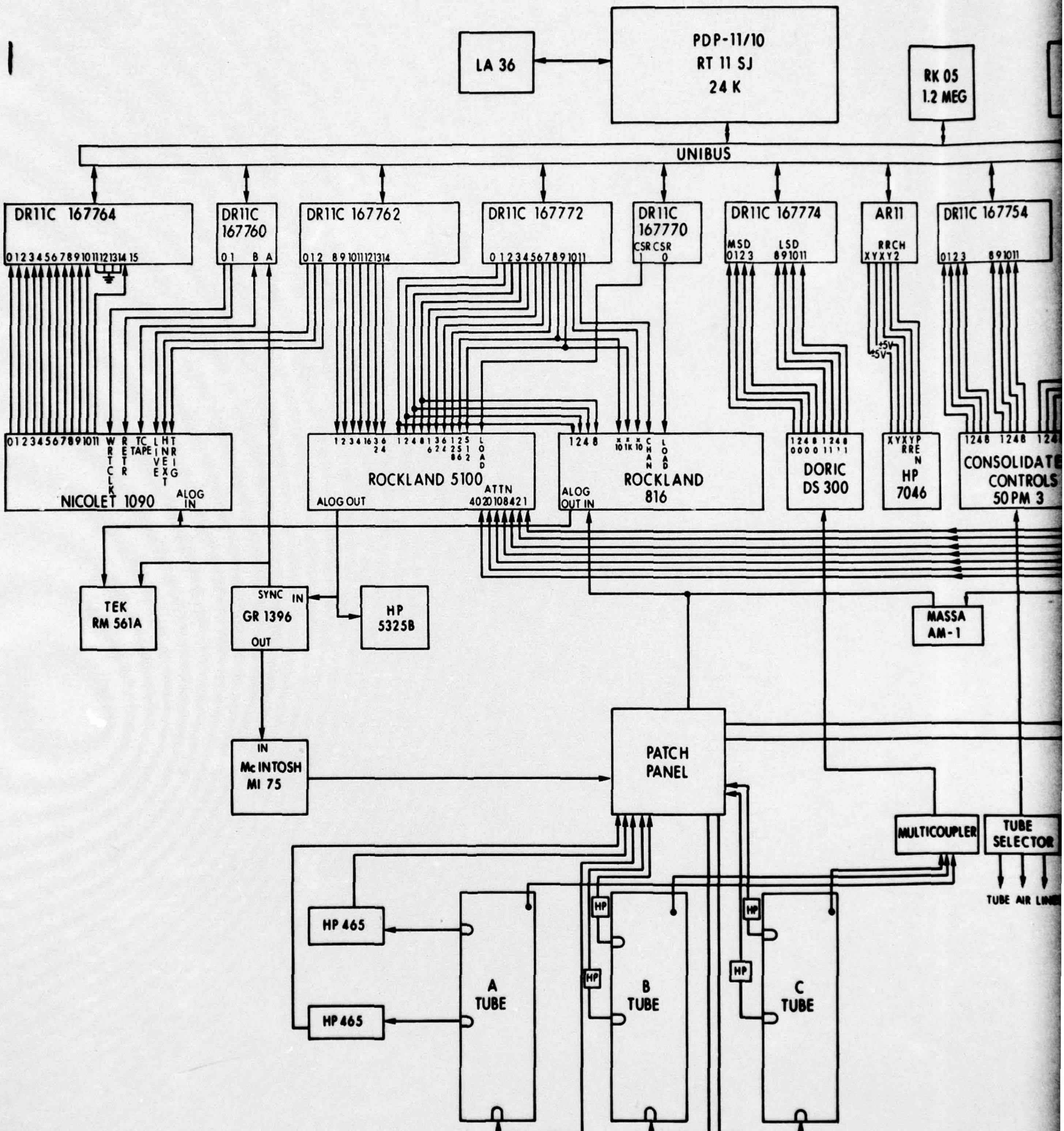

Figure 2 - Sonic Pulse Tube Data Acquisition System

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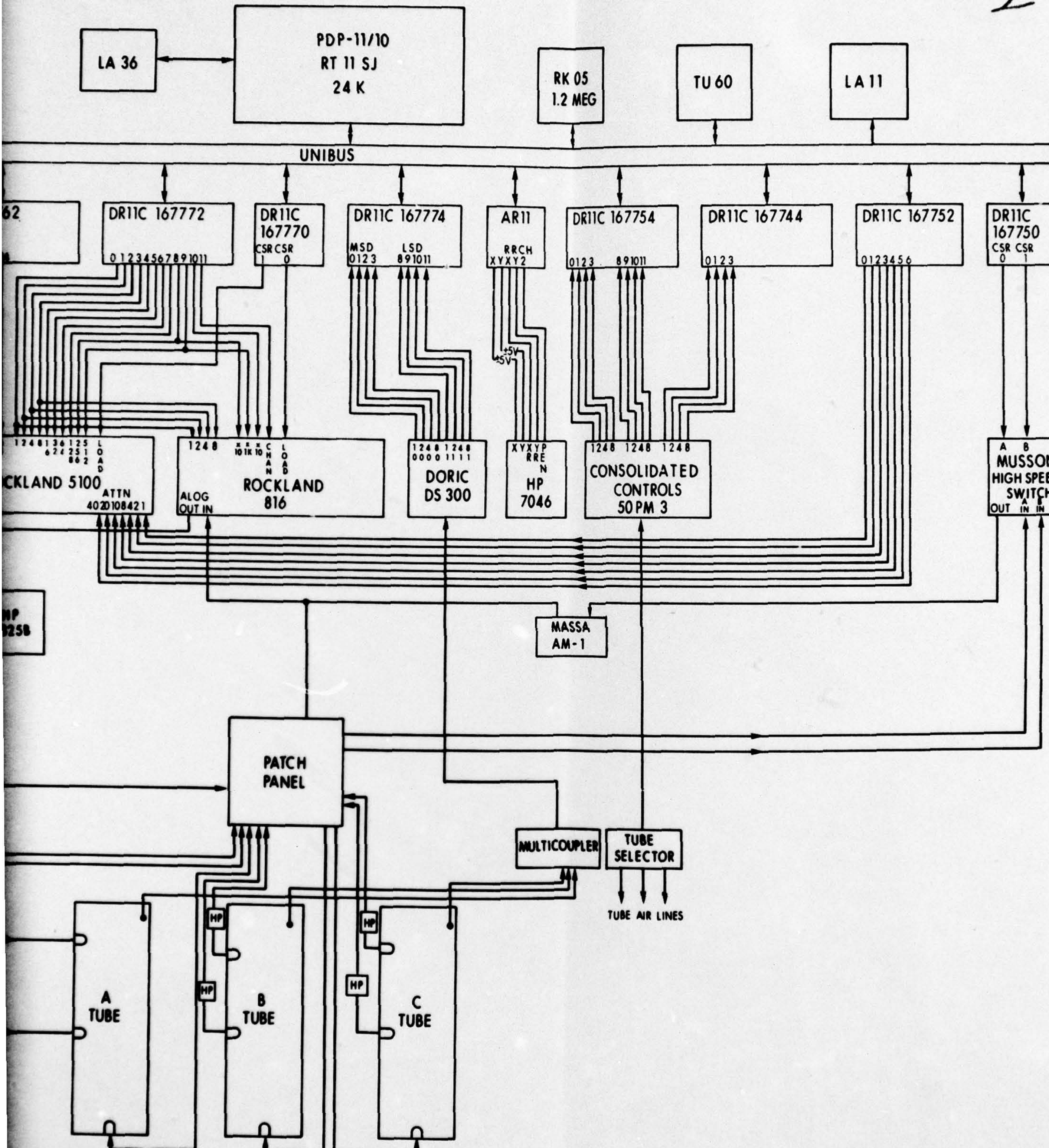

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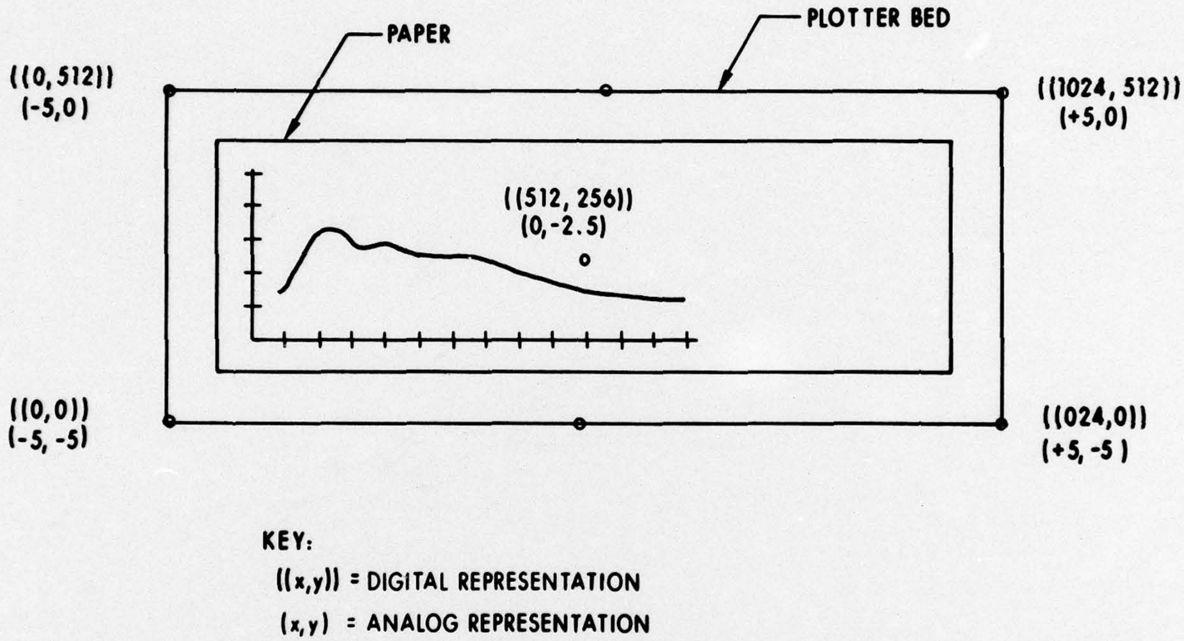


Figure 3
Digital-to-Analog Correspondence of the Plotter Scale

APPENDIX A

SPECIFICATIONS OF THE NICOLET DIGITAL OSCILLOSCOPE MODEL 1090/93

specifications
1090 main frame

Memory: 4096 words, 12 bit words.

CRT: 8 cm x 10 cm rectangular tube.

Display Expansion: Separate controls for horizontal and vertical axes. Each switched on or off and expanded around a selected point x2, x4, x8, x16, x32, x64.

Cross Hairs: Positions of vertical and horizontal lines are controlled separately and target the point around which expansion will take place. In the unexpanded display the cross hairs are moved across the data. In the expanded mode the data is moved while the cross hairs remain center screen. (Present in hold mode only.)

Numerical Display: Three switch selections.
Coordinates: Where the vertical cross hair intersects the information determines the value of the decimal display at the bottom of the screen; time from the trigger and volts recorded at that point in time are indicated.
Dimensions: The decimal display indicates time and volts of the screen dimensions as these are changed by expansion controls.
Off: No decimal display.

Memory Store/Display: All 4096 words of memory can be used, or divided into two 2048 word parts, or four 1024 word parts for record, display and readout modes. When different information is recorded in halves or quadrants these records are displayed superimposed by placing the memory switch in All.

Display A/B, Y/T, B/A: In the usual Y/T position information is displayed on the CRT with time as the horizontal axis. When the switch is placed in the A/B position, two records can be displayed in an X-Y mode, one as a function of the other. In this case B input is used as the horizontal axis. With the switch in the B/A position, A input is used as the horizontal axis. Only vertical expansion is available in the A/B and B/A displays.

Erase: Push button for manual erase of memory if desired.

Non-Invert/Invert: In the release mode the polarity of the input can be reversed or not. In the hold mode "data move" will add with the "non-invert", and subtract with the "invert" selection.

Data Move: When held down, will continually add or subtract a constant to Y values selected by the Memory switch. (It will not function with horizontal expansion turned on.)

Auto Center: When turned on and expansion switches off the horizontal cross hair will move to the Y value intercepted by the vertical cross hair; if the vertical expansion is on and expanded x2 or more the stored data will move on the display so that the Y value intersected by the vertical cross hair is moved to the center of the screen.

Size: 20.5″ length, 10.25″ width, 12.25″ height.

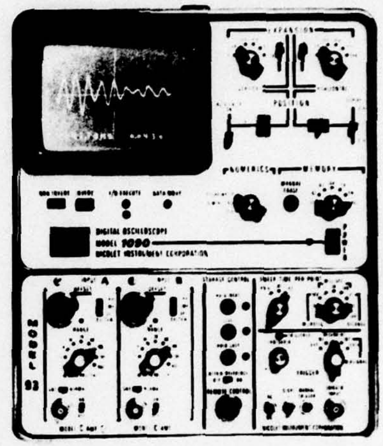
Weight: 45 pounds including typical plug-in unit.

Digital I/O: Binary out on rear panel connector, TTL compatible. Interface and magnetic tape for reading in and out are available accessories.

Pen: X axis 0-4.5 volts nominal across all of memory, or across any portion chosen for expanded display.
Y axis 0-4.5 volts nominal; speed variable from 2 to 15 addresses per second standard. Other speeds available on request.
Pen lift signal available on I/O connector; nominal ground during readout, nominal +4 volts otherwise.

Temperature: Ambient temperature 40° to 110° F. Storage temperature −30° to 150° F.

Power: 100 to 253 volts, 48-440 Hz. Power consumption 85 watts.



model 93 plug-in

Two Input Channels: Amplifier modules may be mixed or matched

Single Ended Amplifier/Attenuator

Input Ranges: ±1, ±2, ±4, ±10, ±20, ±40, ±100, ±200, ±400 volts full scale. Impedance 1 megohm, 47 pf.

D.C. Offset: Nominally 90% of range setting, ten turn pot control.

Maximum Input Signal: 10 Volts, using ±1V sensitivity; ±400V otherwise.

Differential Amplifier/Attenuator: Specifications *to be published. Please contact the plant for* details.

Analog to Digital Converter: 12 bits, monotonic

Measurement Accuracy: (At normal room temperature range).

Voltage:

1. Scale calibration: 0.25% of range. Front panel adjustable.
2. Other errors: nonlinearity, misadjustment and noise, less than 0.05%.
3. Drift ±0.25% per 5°F after warm up.
4. Sample and Hold Aperture time variation: Nominally 5 nanoseconds for single signal.
5. Signal Channel Crosstalk 0.05% or less.

Time:

1. Calibration: ±0.02%
2. Drift: ±0.01% per year.

Trigger Signal:

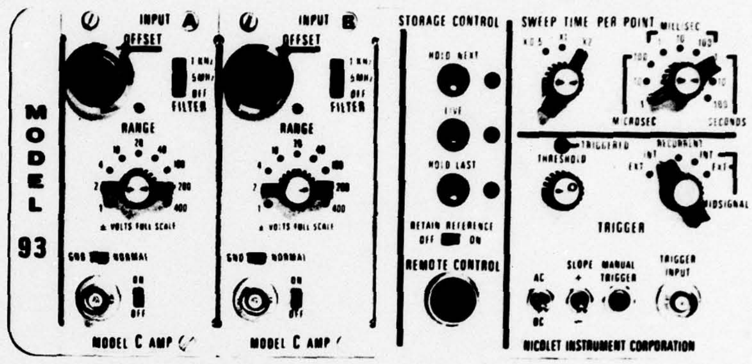
Range: ±0.25 to ±5V, a.c. or d.c. coupled.

Maximum allowable: 25V

Trigger occurs on transition through an adjustable threshold level.

External trigger input impedance is nominally 1 megohm.

Sweep Trigger Insensitive Times: At slow sweep speeds (100 usec per point or slower) there is essentially no "dead" time between sweeps. At faster sweep speeds, a dead time of from 5.5 milliseconds to 64 milliseconds exists depending upon the number of points used per sweep and the number of points displayed on the CRT. During this time, following acceptance of a signal into memory, the instrument is insensitive to incoming sweep trigger pulses.



Sweep Time Per Point: Ranges of 0.5, 1, 2, times 1, 10, or 100 microseconds, milliseconds, or seconds, one or two channels, simultaneously.

Push Button Controls:

Manual Trigger: Simulates electrical trigger signal.

Hold Last: Stores the information which followed the last trigger.

Hold Next: Stores the information which will follow the next trigger.

Live: Accepts the next valid trigger and records new information presented to the input.

Retain Reference: Displays stored information while also viewing "live" signals.

Remote Control: Hold and release commands ±5 volts normal level, 0 to 0.5 volts, or switch closure to initiate action.

Filter: Low pass; nominally—3dB at specified cutoff, 0.5 MHz or 1 kHz.

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